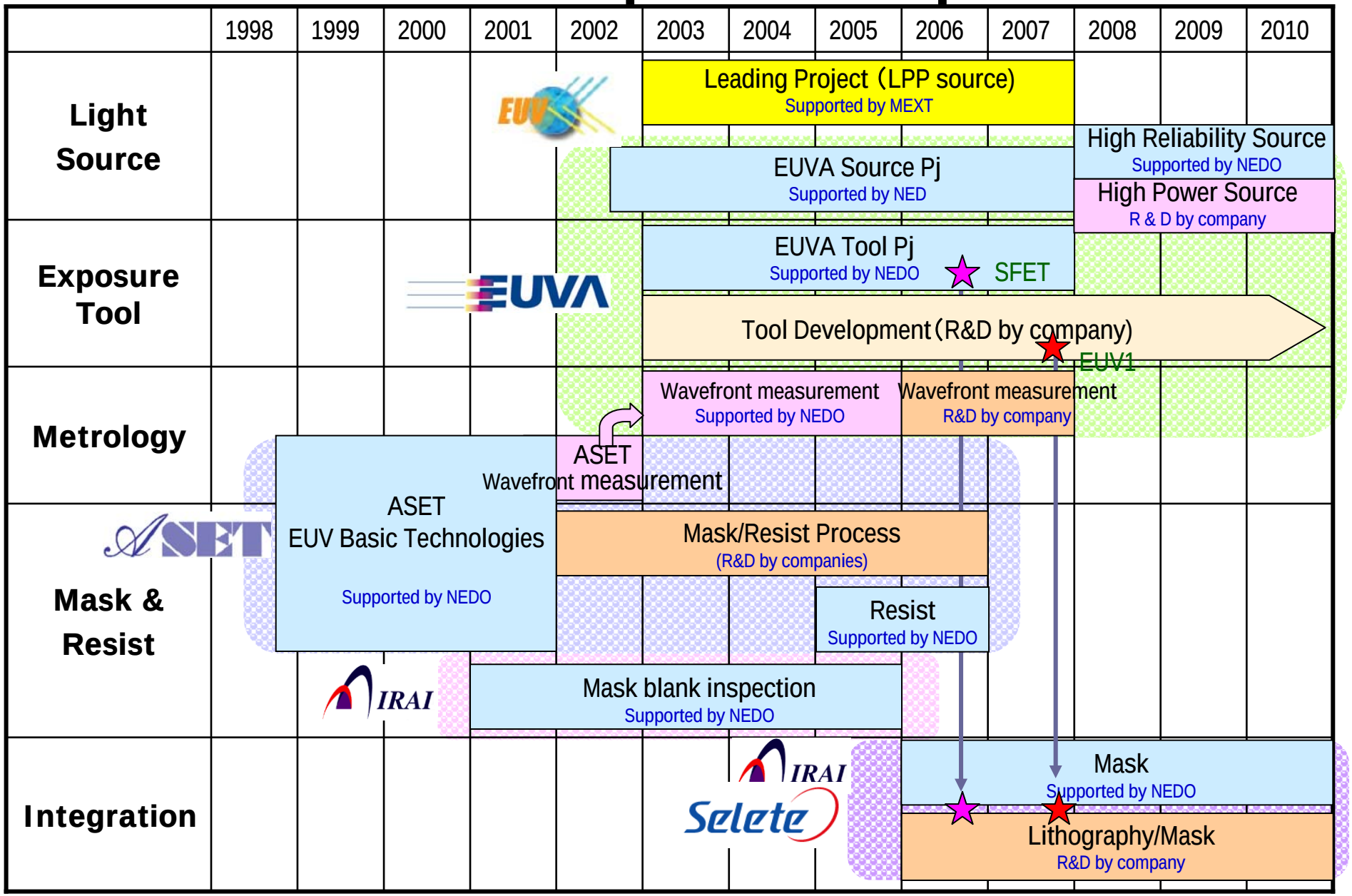
EUVL Development in JAPAN

～ Challenge, Idea, and Latest Achievement ～

Iwao Nishiyama

Semiconductor Leading Edge Technologies, Inc.

EUVL Development in Japan



Source

First proposal of Tin Target

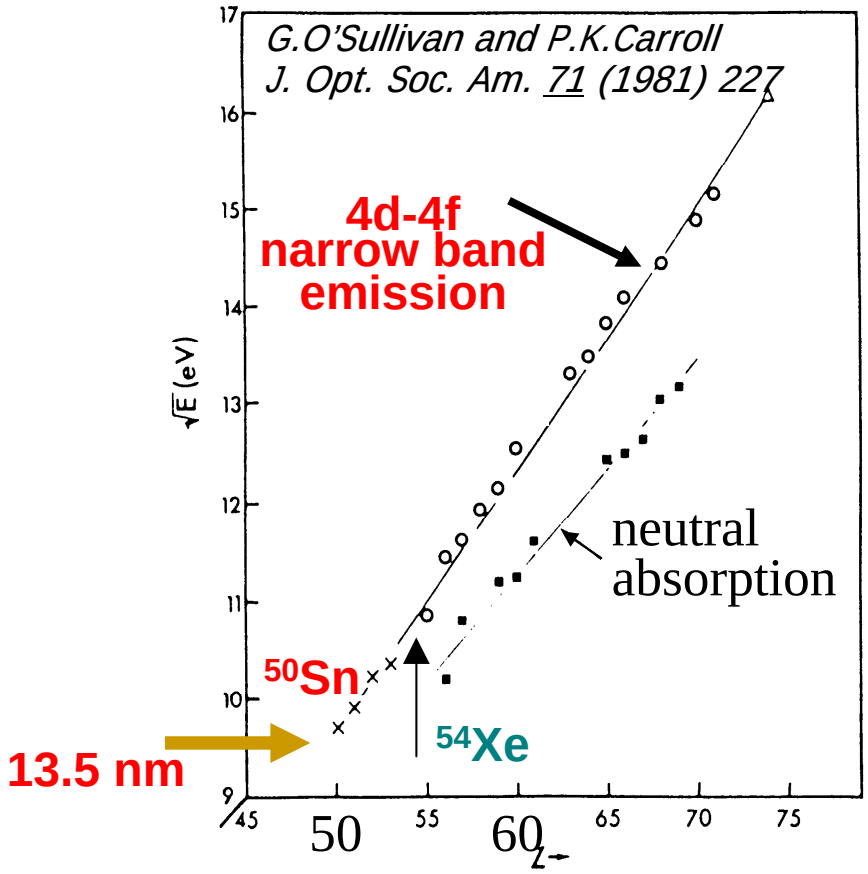
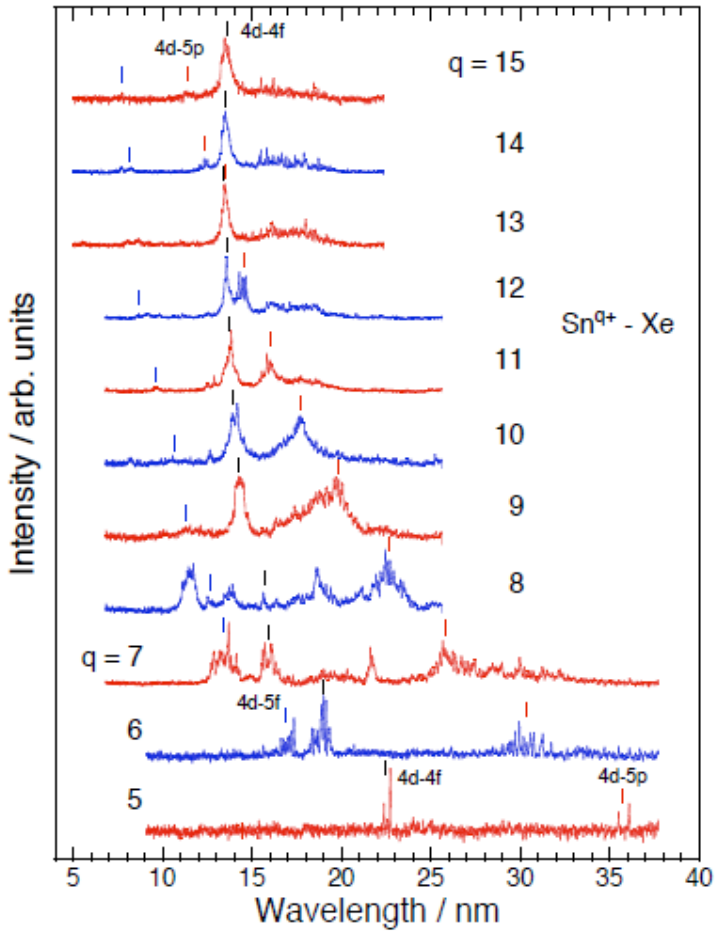


Fig. 5. Dependence of $4d-4f$ transition energies on atomic number Z. Open circles, this paper (Table 1); crosses, data from plasmas of tin through iodine; open triangles, assigned to tungsten in Tokomak plasma[9]; filled squares, absorption of neutral vapors.[10]

Tomie, EUVL Workshop 2000 (San Francisco)



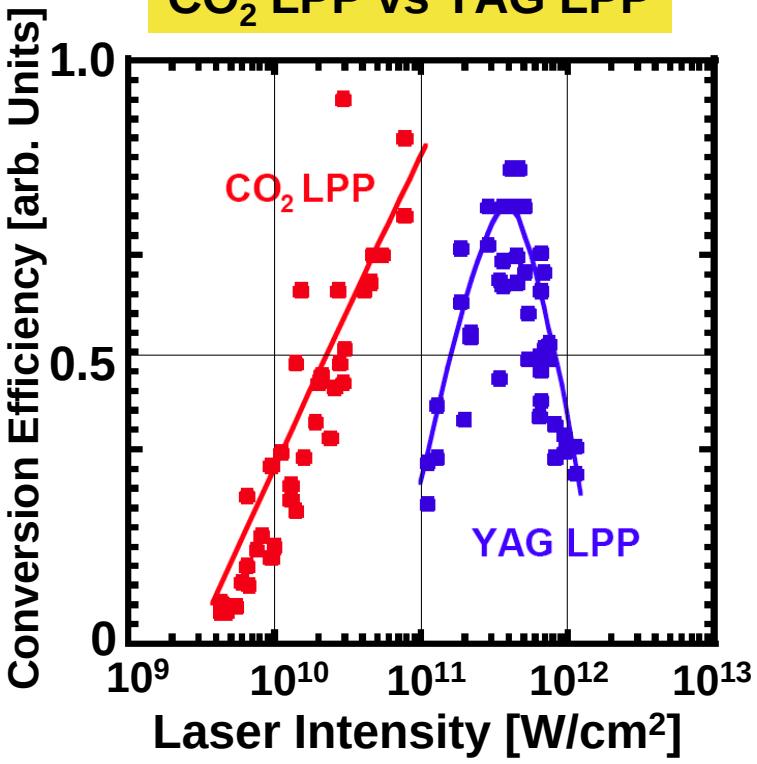
Tanuma, EUVL Symposium 2006 (Barcelona)

High CE of Tin target was firstly proposed.

Charge selective spectra were directly measured.

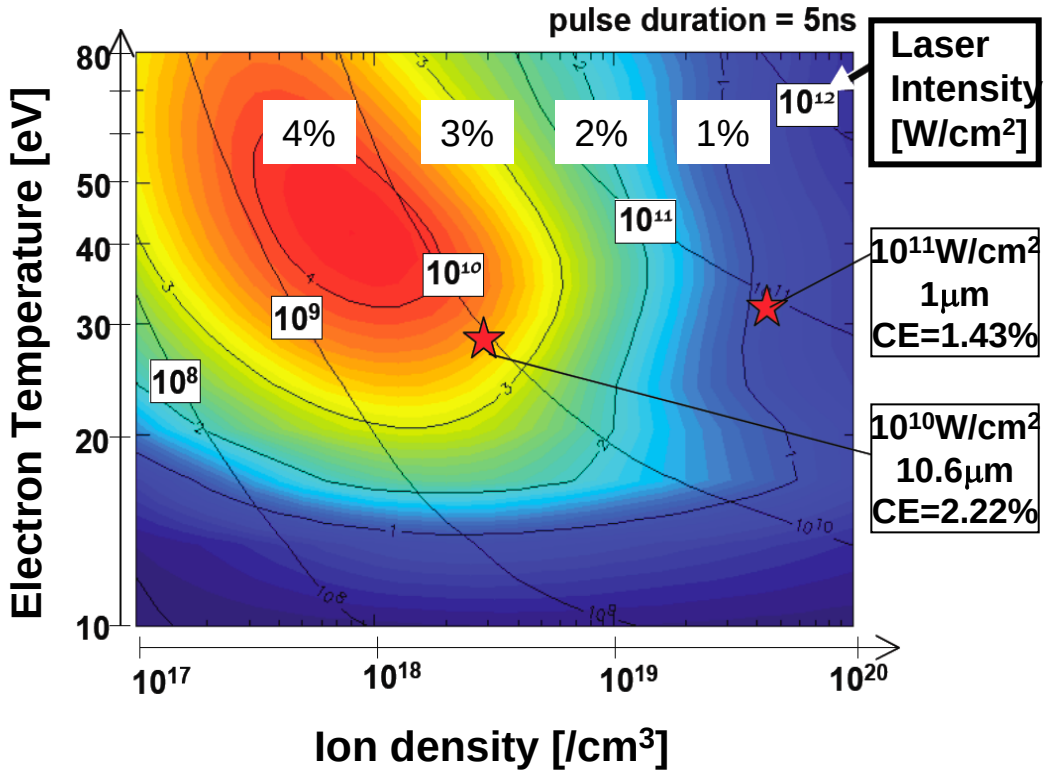
Conversion efficiency of CO2 LPP vs YAG LPP

CO_2 LPP vs YAG LPP



Okada, Jpn. J. Appl. Phys. (2004) L585
Tanaka, Appl. Phys. Lett. 87 (2005) 041503.

Density-temperature map of 13.5-nm EUV conversion efficiency

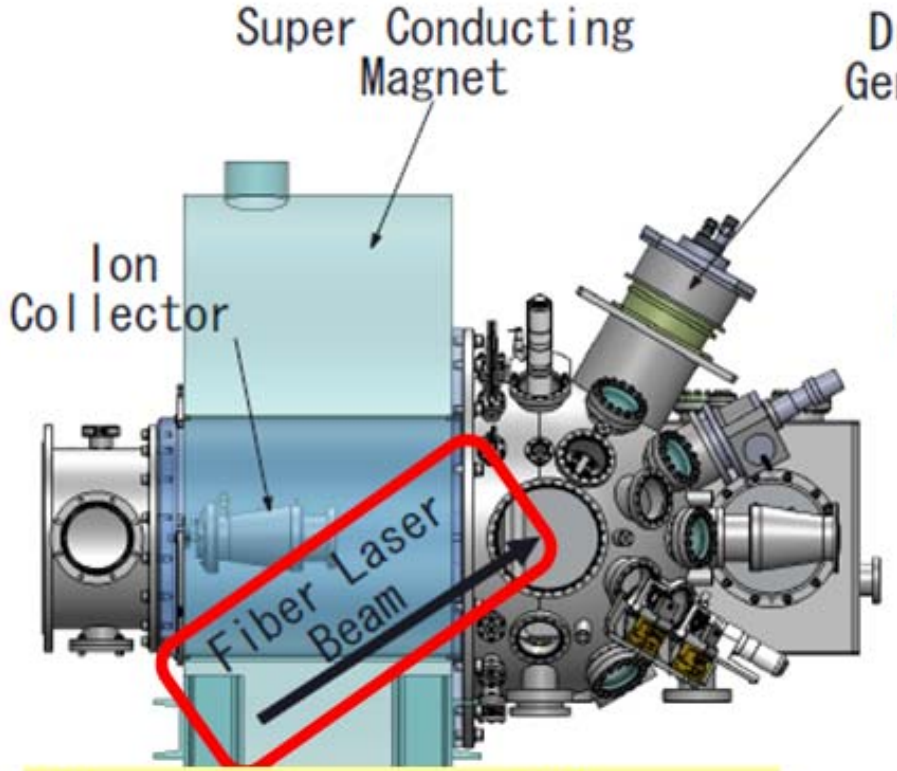


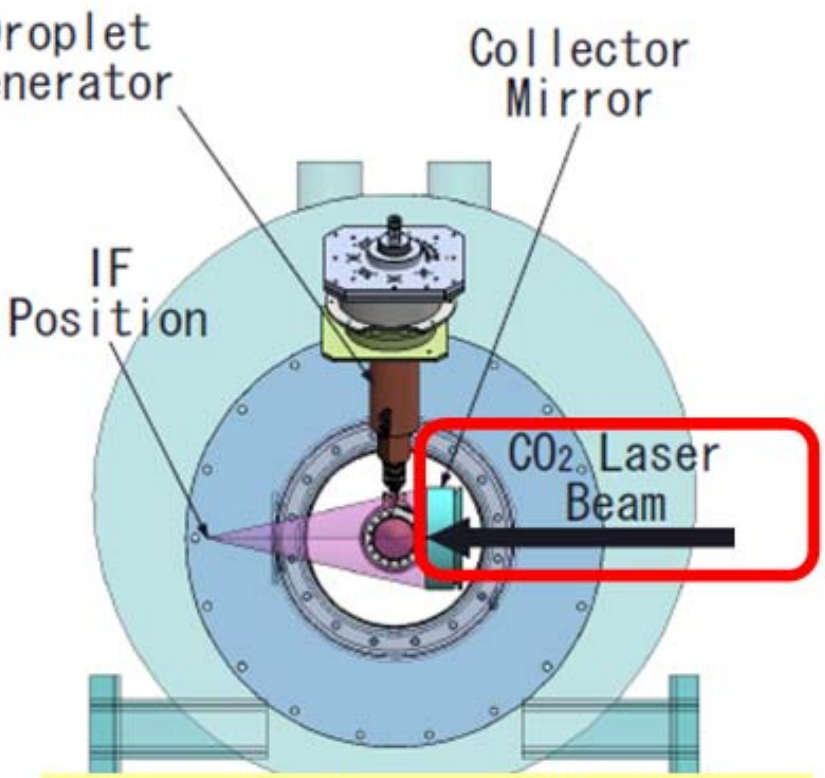
K. Nishihara, EUVL Symposium 2004（Miyazaki)

Feasibility of CO2 laser driven LPP was firstly demonstrated.

ETS EUV chamber configuration

IRAI





Pre-pulse laser crash Tin droplet, which enables efficient absorption of main pulse power. CE increases up to 2.5%.

Main pulse beam quality is improved at 7.9kW operation.

KOMATSU

EUVA

System operation data (1)

	2009. Oct. Prague	2010. Feb. San Jose	2010. Jun. Hawaii
Brightness (@I/F)	**25 W**	**69W**	**104 W**
Repetition rate	100kHz	100kHz	100kHz
Pulse energy	0.25mJ	0.69mJ	1.04mJ
Duty cycle	**10%**	**20%**	**20%**
Max. non stop op. time	**3 hr**	**1h**	**-**
Experiment time	**7 hr**	**-**	**-**
Average CE	**1.5%**	**2.3%**	**2.5%**
Dose stability (simulation)	**-**	**(+/-0.15%)**	**(+/- 0.15%)**
Droplet diameter	**60μm**	**60μm**	**60μm**
CO2 laser power	**5.0kW**	**5.6kW**	**7.9kW**

Optics

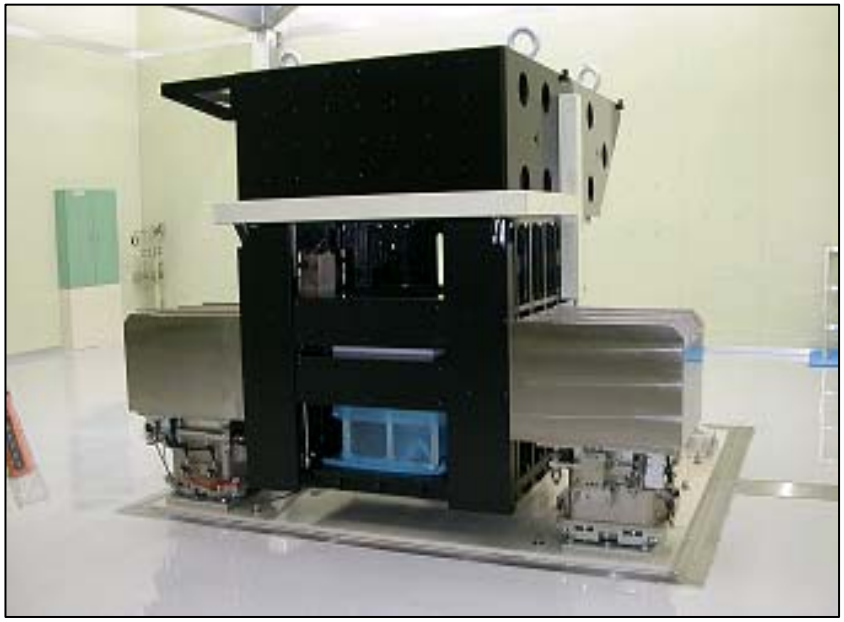
Metrology for aspherical mirror

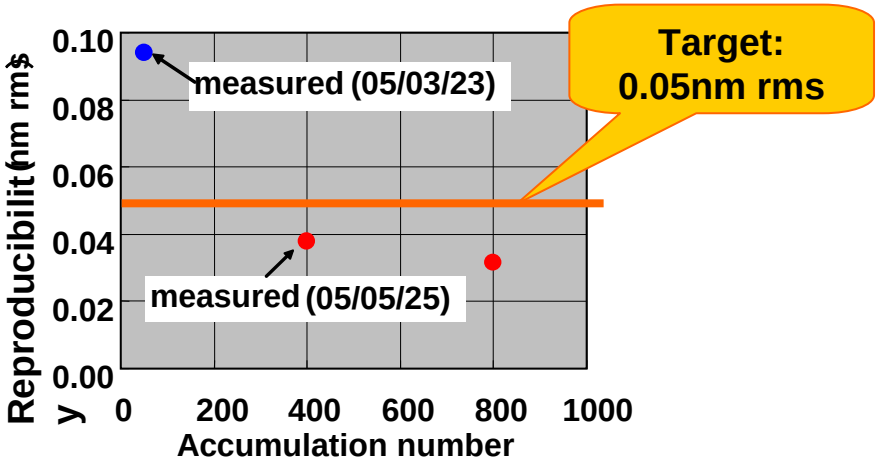
Visible PDI for High Accuracy

PDI: Point diffraction interferometer

K. Ota, Proc. SPIE 4343 (2001) 543

High precision interferometer for production

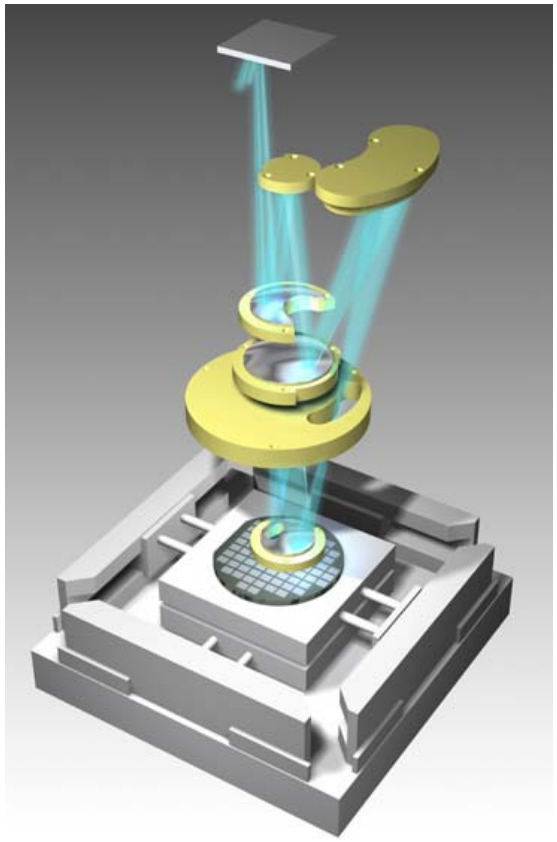




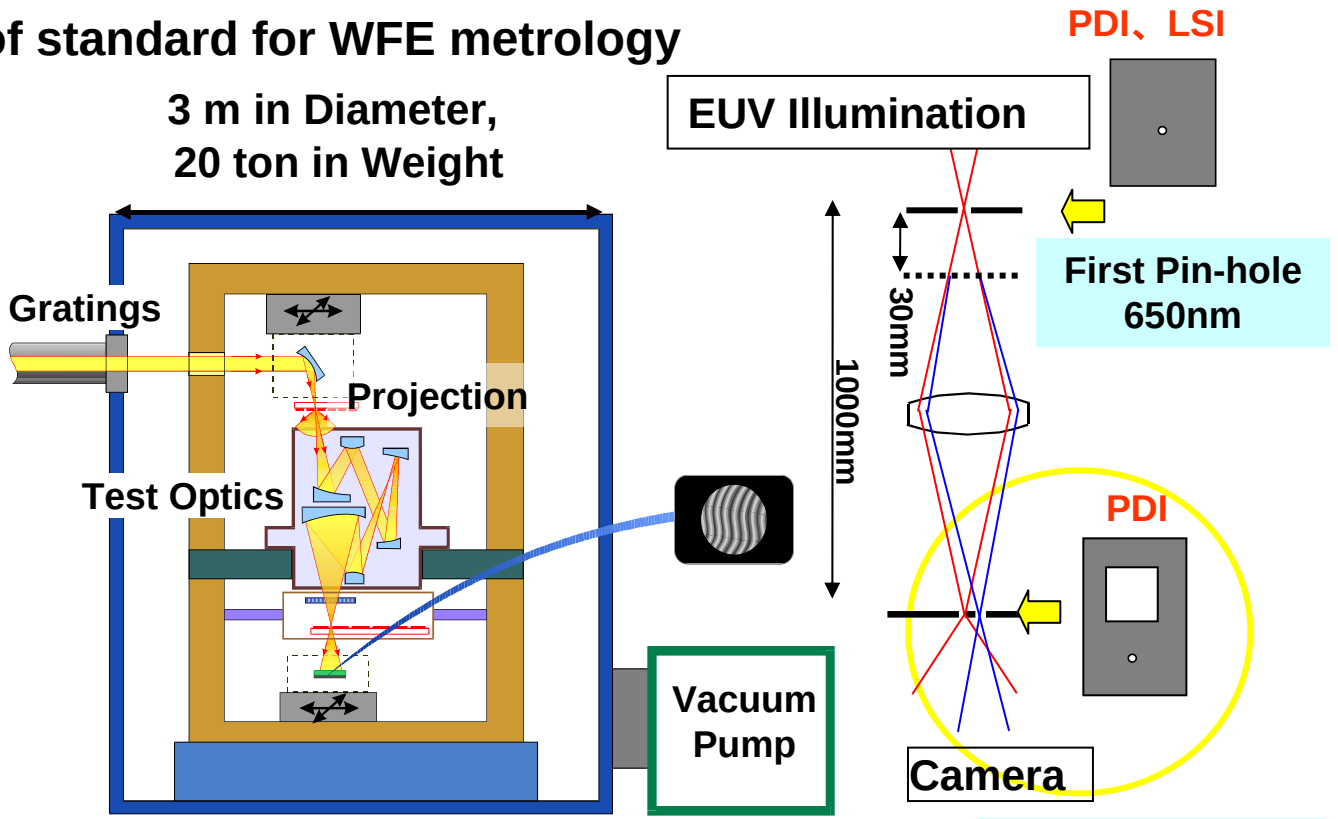
New-concept interferometers were developed for λ/30 projection optics

At-wavelength wave-front metrology of optics

Purpose：Development of standard for WFE metrology

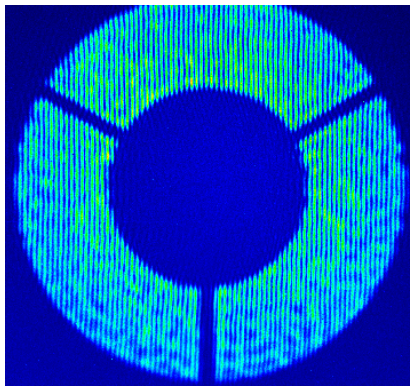


Schematic View of 6 Mirror System



The System was installed at Hyogo Pref. Univ.

Accuracy of 0.1nm rms was achieved



Large Window and 2nd Pinhole of 50-80nm

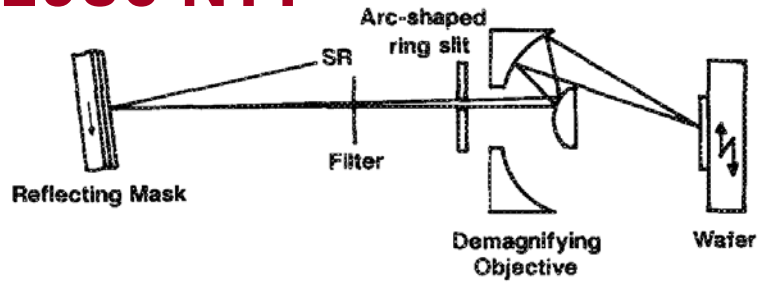
Interference fringes obtained by PDI

Tool

EUVL Tool development in Japan

- Small Field Tool -

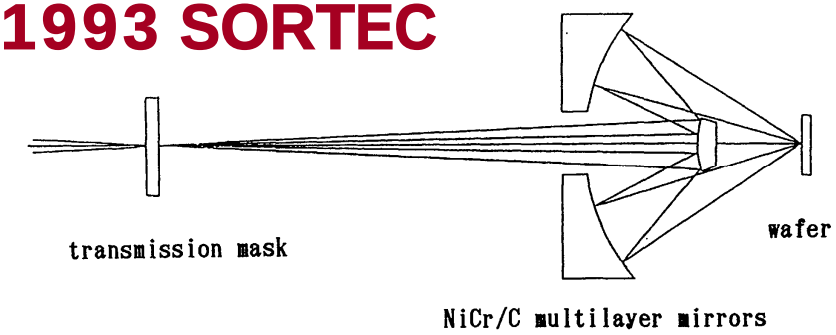
1986 NTT

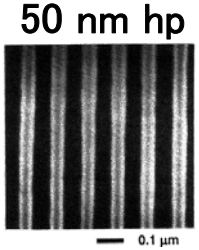


5X, 8X Schwartz Child, 11nm/12.4 nm

H. Kinoshita, Proc. Fall Mtg. Jpn Soc. Appl. Phys. (1986)
H. Kinoshita, J. Vac. Sci. Technol. B7(1989) 1648

1993 SORTEC

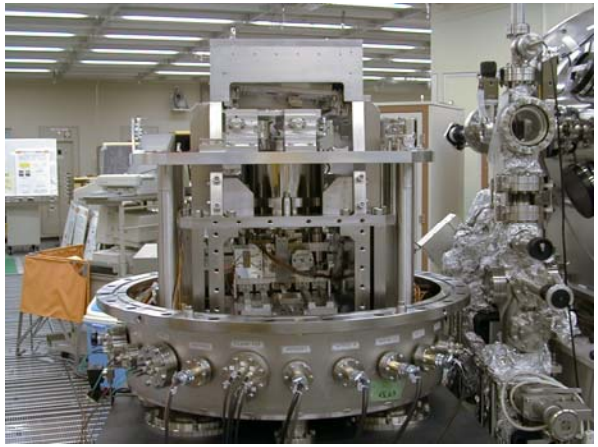




32X Schwartz Child, 13 nm / 4.5 nm

H. Oizumi, 1993 Jpn J Appl. Phys. 32 (1993) 5914
H. Nagata, Jpn. J. Appl. Phys. 33 (1994) L1192

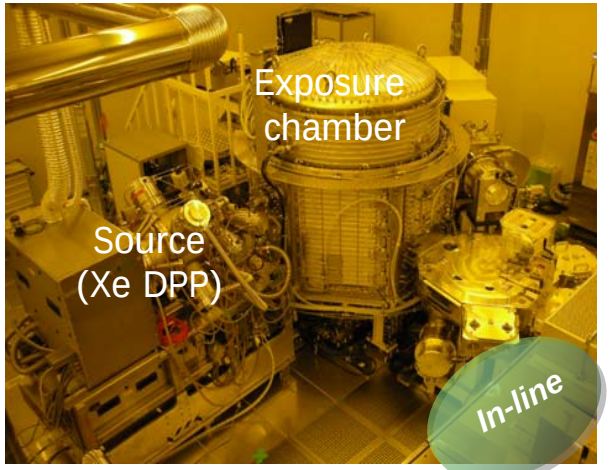
2001 ASET（HiNA） Nikon



5X NA0.32

T. Oshino, Proc. SPIE 5037 (2003) 75
H. Oizumi, Proc. SPIE 5751 (2005) 102

2007 Selete（SFET） Canon



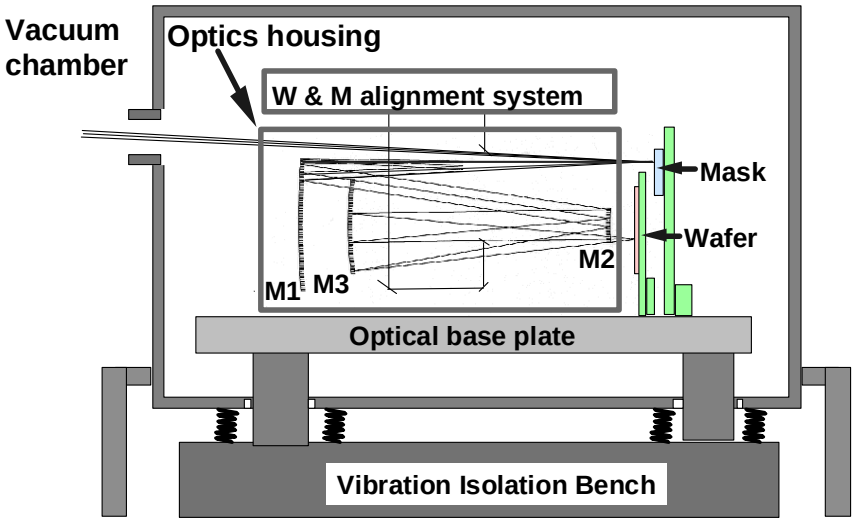
5X NA0.32

H. Tanaka, EUVL Symposium 2007 (Sapporo)
K. Tawarayama, Jap. J. Appl. Phys. 47 (2008) 4866

EUVL Tool development in Japan

- Full Field Tool -

1997 HIT(ETS)



5X, NA 0.1, SR Source
3 aspheric mirror system

T. Watanabe, Jpn. J. Appl. Phys. 36 (1997) 7597

2008 Nikon-Selete(EUV1)

4X, NA 0.25, Xe-DPP
6 aspheric mirror system

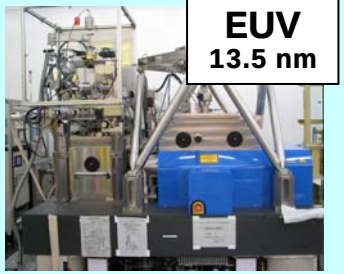
I. Mori, Proc. SPIE 6921 (2008) 692102-1

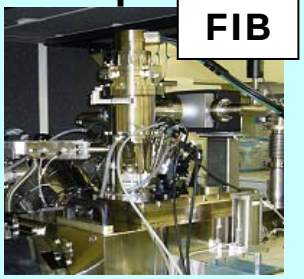
Mask

EUV Mask Development in Selete

Mask Infrastructure

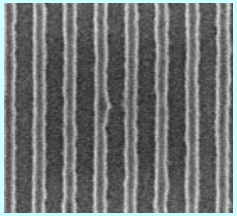
Actinic Blank Inspection	Pattern Inspection	Pattern Repair
EUV 13.5 nm	DUV 199 nm	FIB

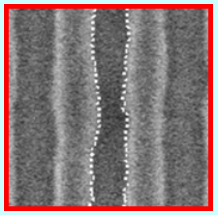


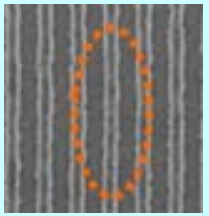


Mask defect printability

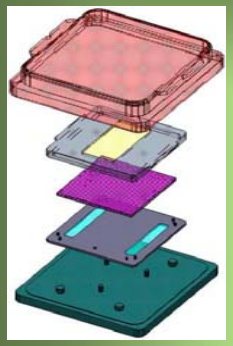
	Phase defect	Pattern Defect	Defect repair
Mask pattern			
Printed Image			







Particle free mask handling



Double pod

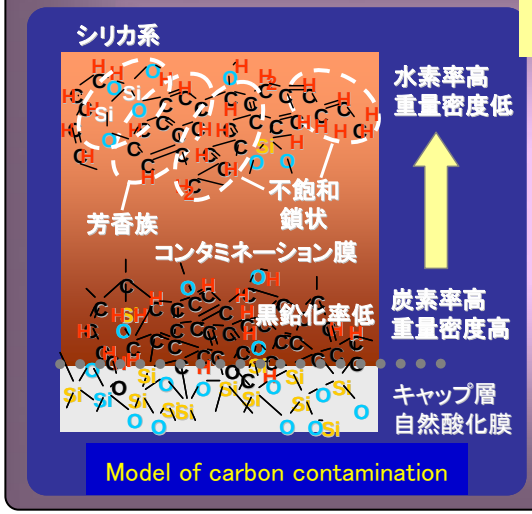
MPE-tool

Blank Inspection M3350

0.008 defects/transfer
⇒ 0.002particlse/transfer

➢ Semi standardization of double pod

Contamination control



Model of carbon contamination

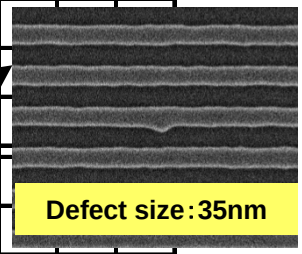
- Carbon analysis
- Printability
- Cleaning
- Resist outgas

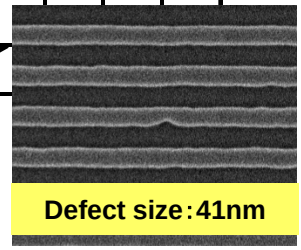
Sensitivity of Pattern defect inspection

Low reflectivity absorber（R4%）

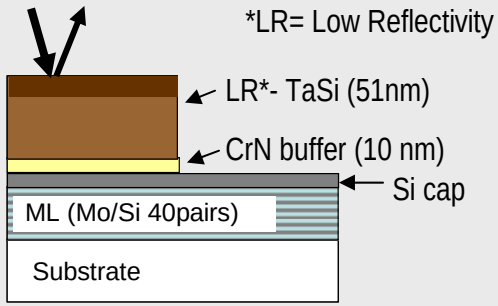
Allowable defect size（10 % CD change）

Base pattern	Defect type	Illumination	Defect size [nm] (Square root of area) 80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5
hp32nm (hp128nm)	extrusion	C-pol.																
		P-pol.																
	intrusion	C-pol.																
		P-pol.																
hp27nm (hp108nm)	extrusion	C-pol.																
		P-pol.																
	intrusion	C-pol.																
		P-pol.																
hp22nm (hp88nm)	extrusion	C-pol.																
		P-pol.																
	intrusion	C-pol.																
		P-pol.																





LR absorber（R4%）

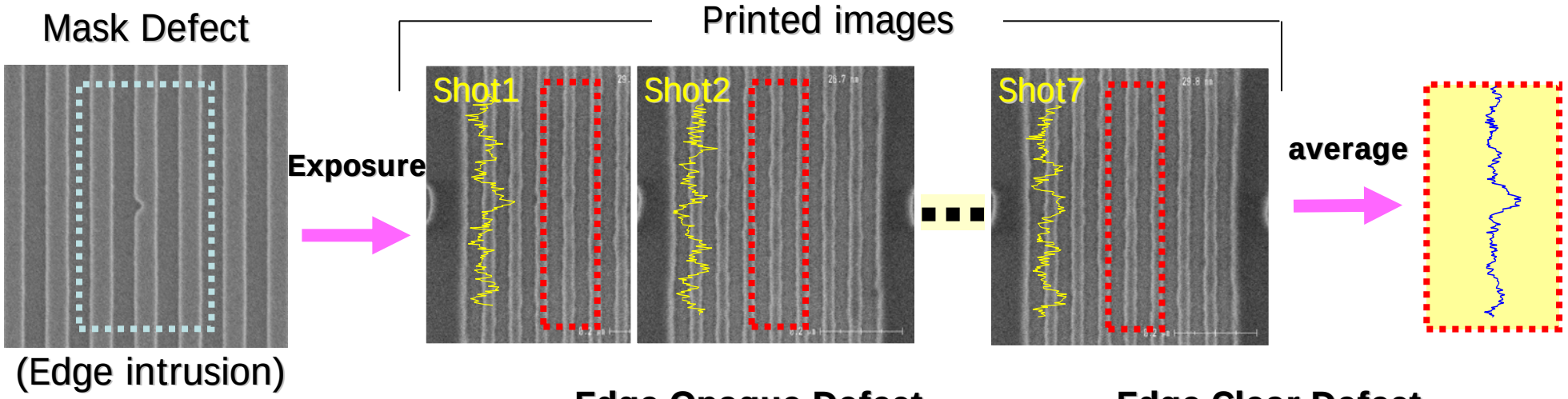


- hp32nm (128nm@mask)
  Both of c- and P- polarizations have enough sensitivity
- hp27nm (108nm@mask)
  p-polarization has enough sensitivity
- hp22nm (88nm@mask)
  p-polarization has potential for hp22nm application, but further improvement is needed

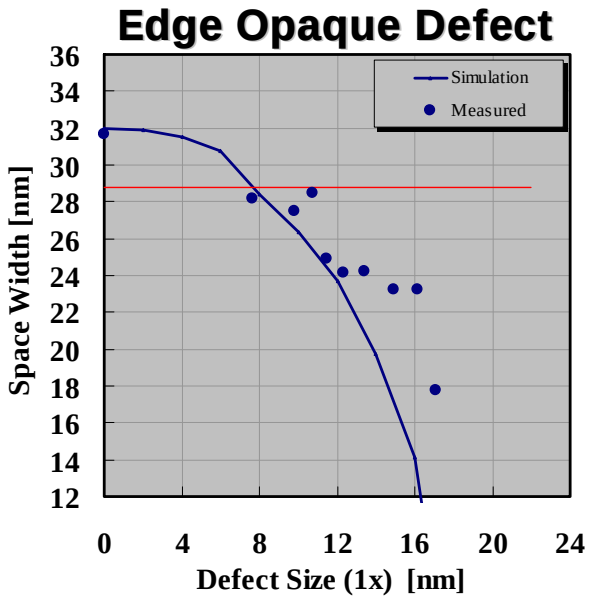
Defect printability test by programmed Defect

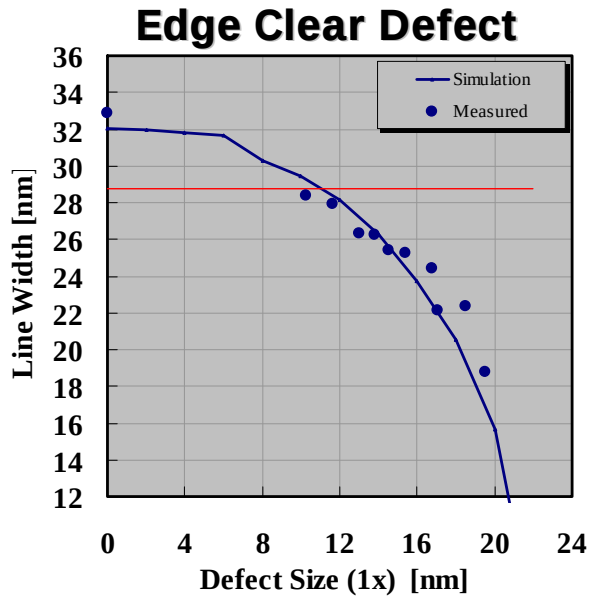
Multi-shot images ware averaged to reduce resist LER

Hp32 nm(7 shots averaging)



Comparison between Simulation and Printed CD change

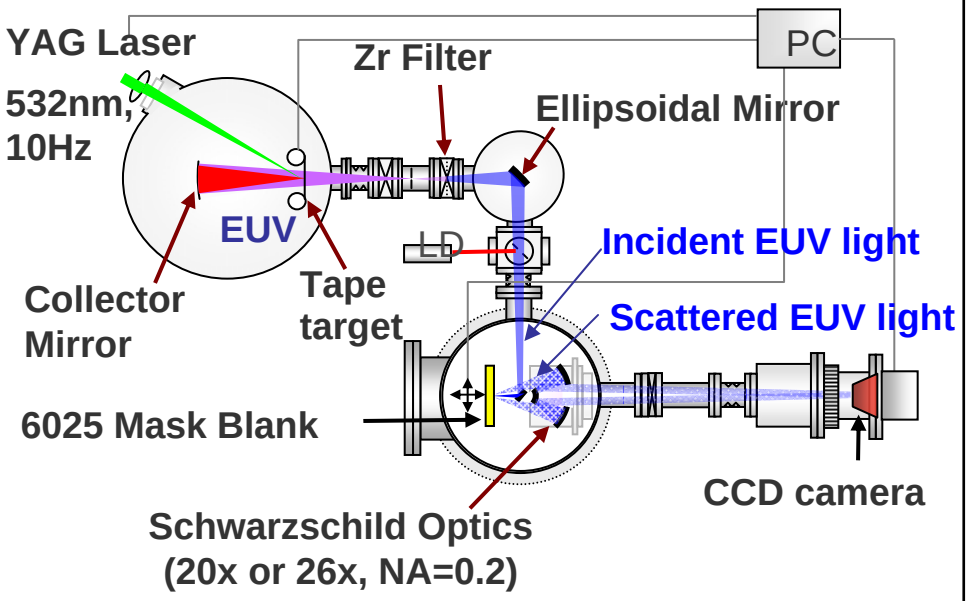




Using the CD Averaging Method, simulated results were verified by actual PD printing test.

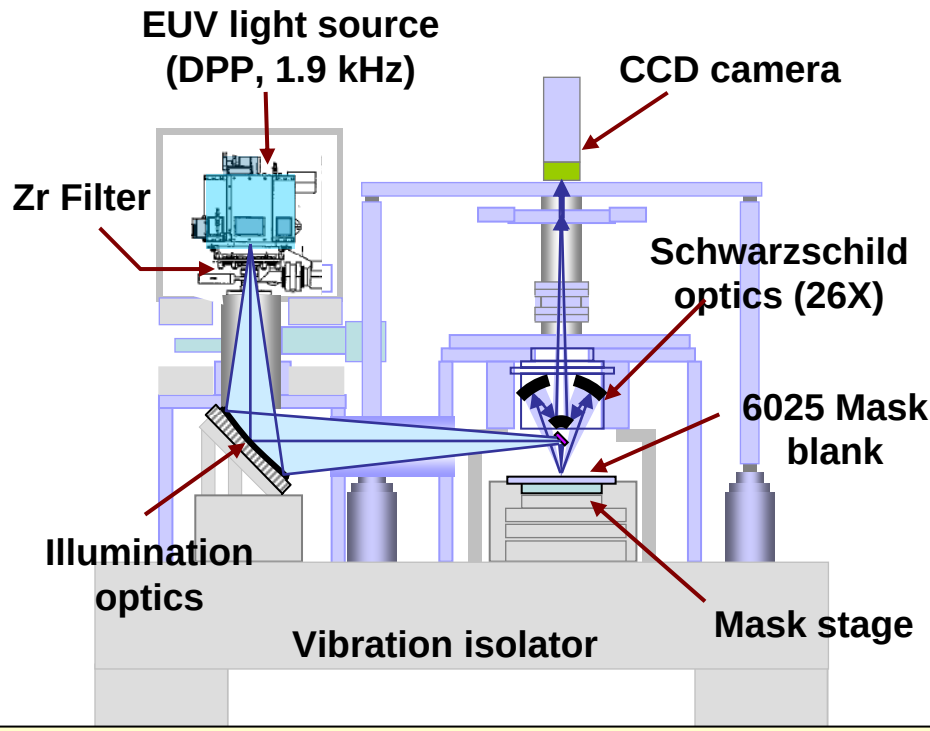
Actinic Blank Inspection

POC tool (MIRAI I and II)
(Top view)



- In house LPP EUV light source (10 Hz)
- Mask stage stroke: X,Y: 10 mm,2 mm (Manual operation)
- Static imaging mode

Full-field Inspection tool
(Front view)



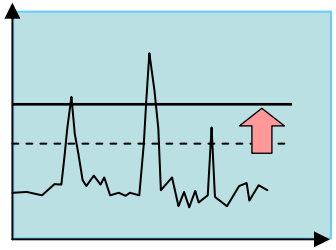
- Commercial available EUV source (1.9 kHz)
- Mask stage stroke: X,Y: 169 mm,169 mm (Automatic controlled)
- TDI mode & Static imaging mode

Detection probability improvement

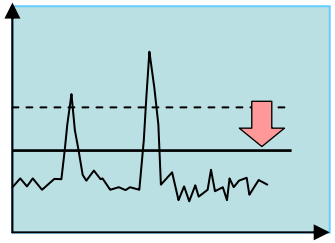
1Q 2009	2Q 2009	1Q 2010

One FOV (0.5mm sq.)

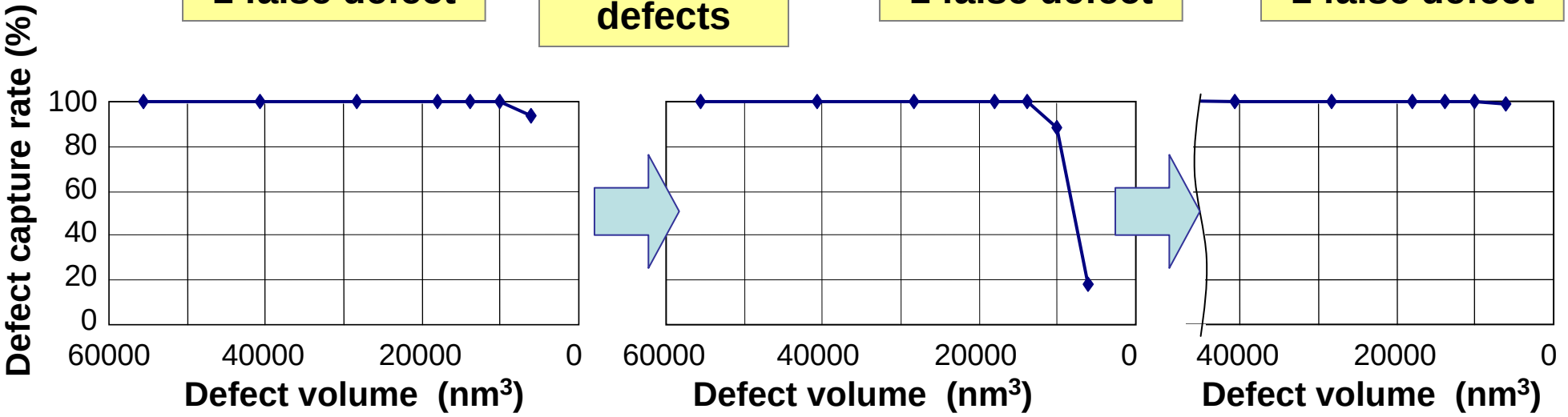
Full-field of mask blank



Noise Filter

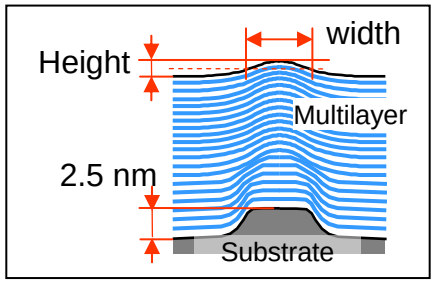


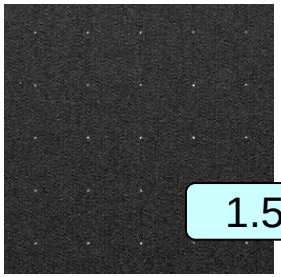
1 false defect → **80,000 false defects** → **1 false defect** → **1 false defect**



Defect Map of Multilayered Blank

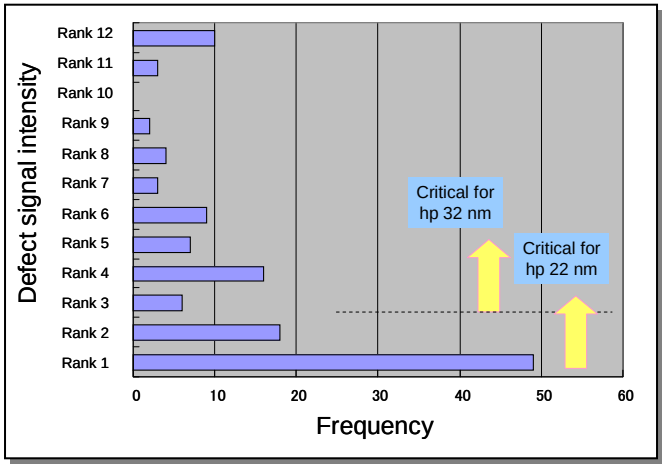
Multilayer phase defect

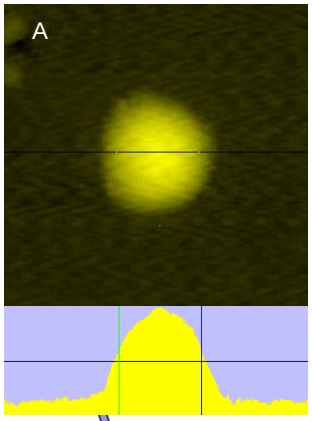




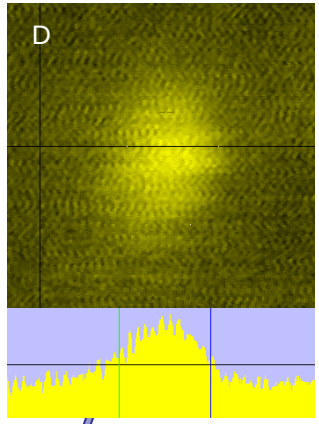
1.5 nmH, 60 nmW

Detection of Programmed defects

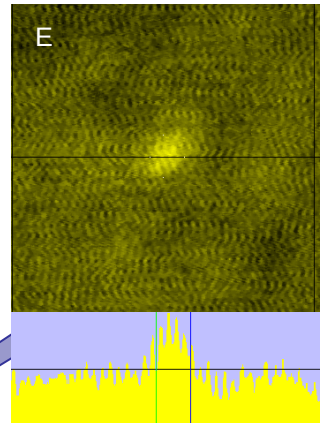




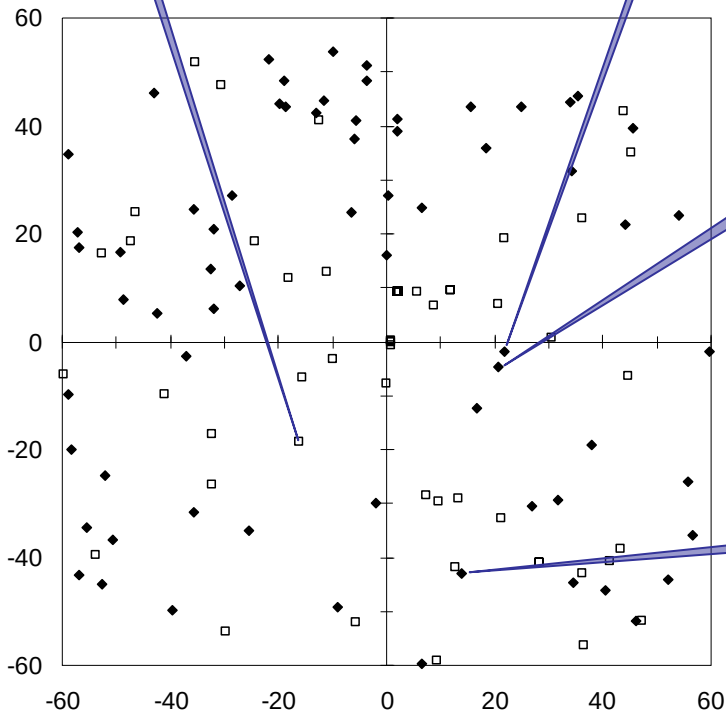
Wx:108nm,
Wy:102nm,
H:1.9nm

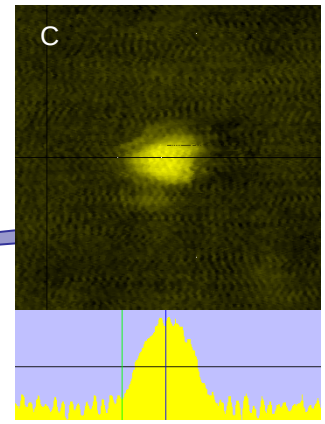


Wx:40nm,
Wy:43nm,
H: 1.8nm



Wx:19nm, Wy:20nm,
H: 1.1nm





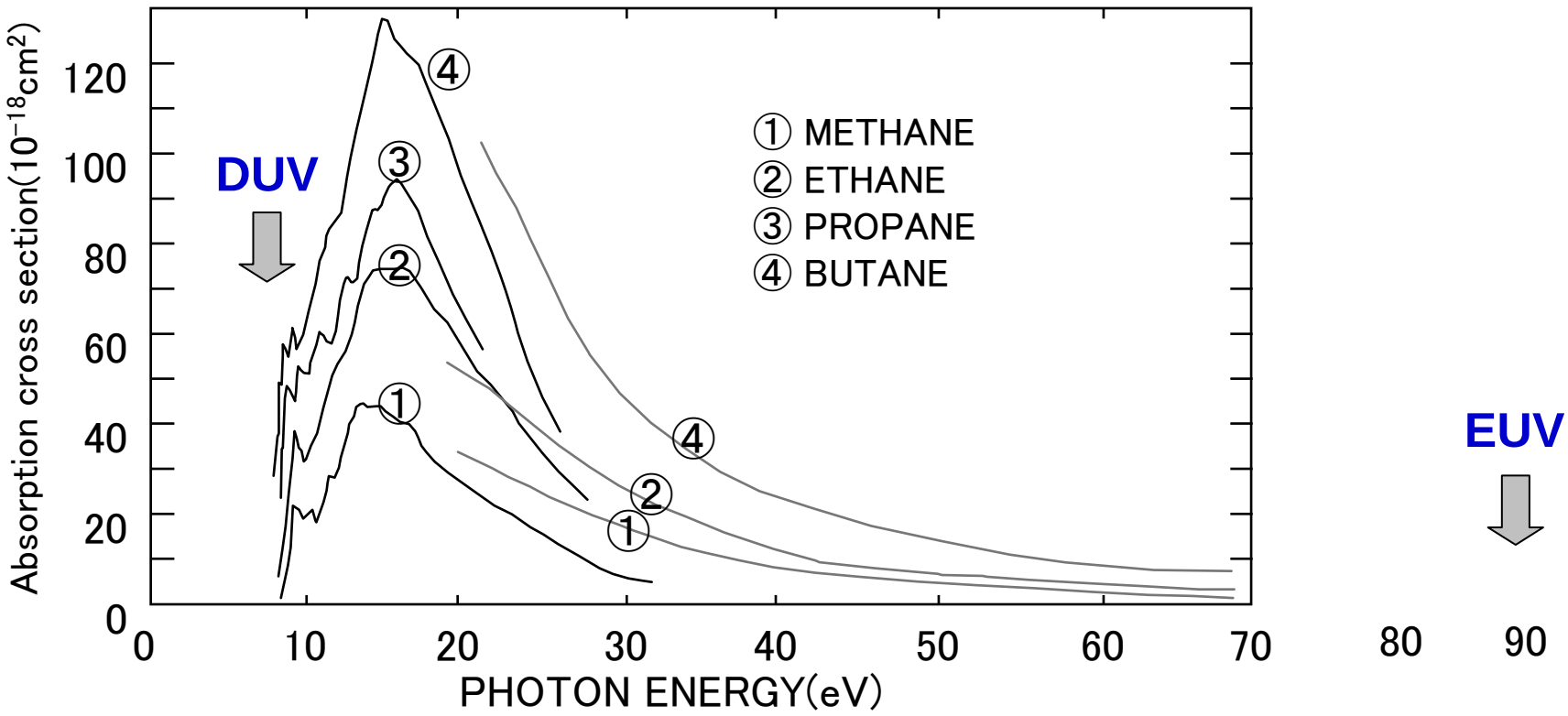
Wx:28nm, Wy:16nm,
H: 2.8nm

□ Defects critical for hp 32 nm
◆ Defects critical for hp 22 nm

Resist

Change of resist chemistry by excitation energy

Absorption spectra of simple organic molecule



DUV resist

- Transmittance is a key factor for DUV lithography. (248 → 193 → 157 nm)
- Reaction occurs by electronic excitation (Photochemistry)

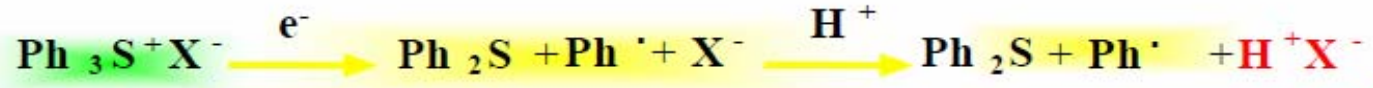
EUV resist

- All DUV and EB resists technologies can be used for EUV lithography
- Reaction occurs by ionization of molecules (radiation chemistry)

Reaction mechanisms of EB and photo resists

· EB resists (Main process)

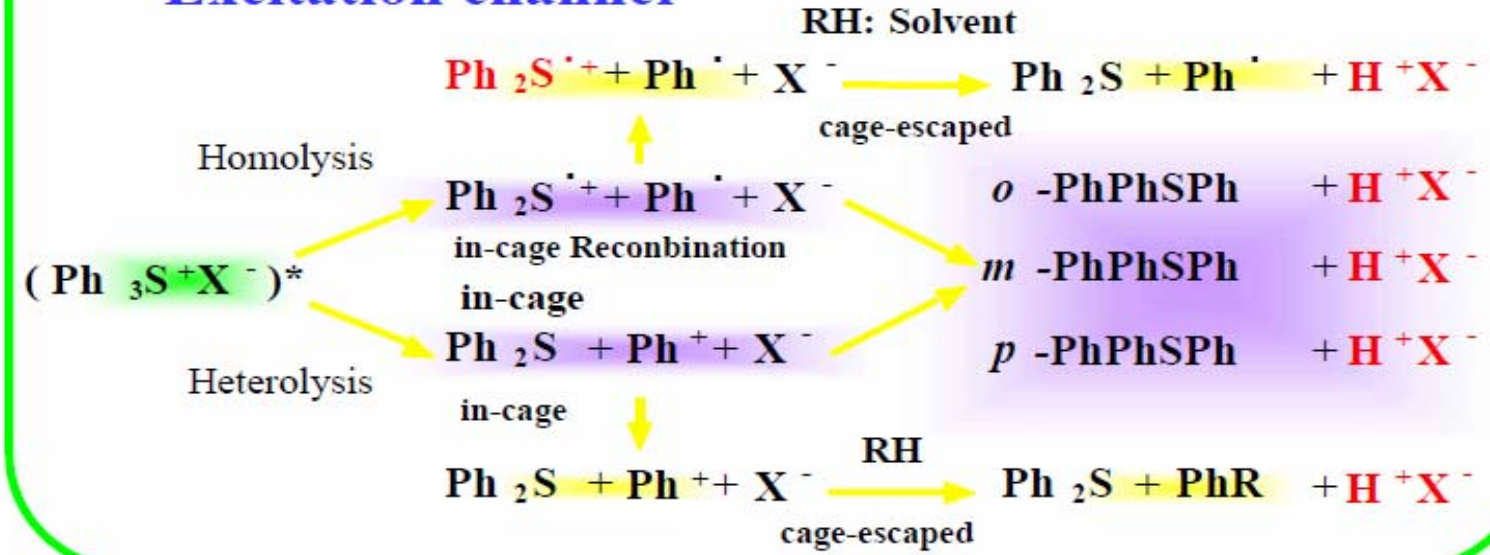
Ionization channel



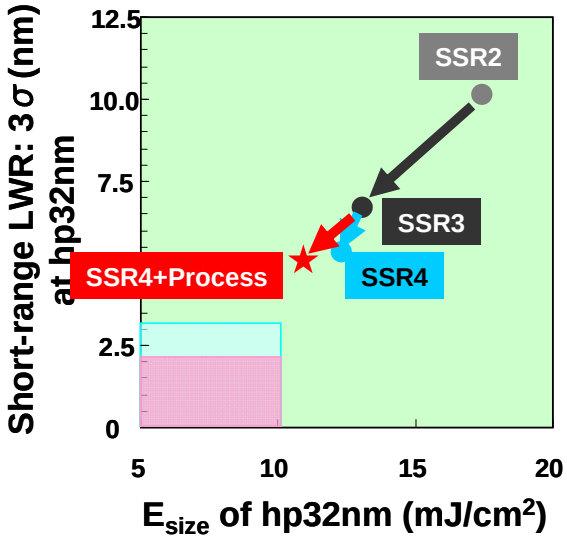
S. Tagawa et. al. SPIE 3999 (2000) 204

·Photoresists (Main process)

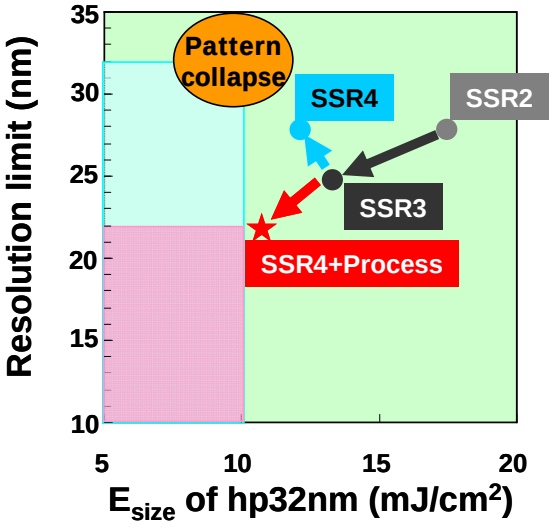
Excitation channel



Pattern Collapse Improvement by New Developer

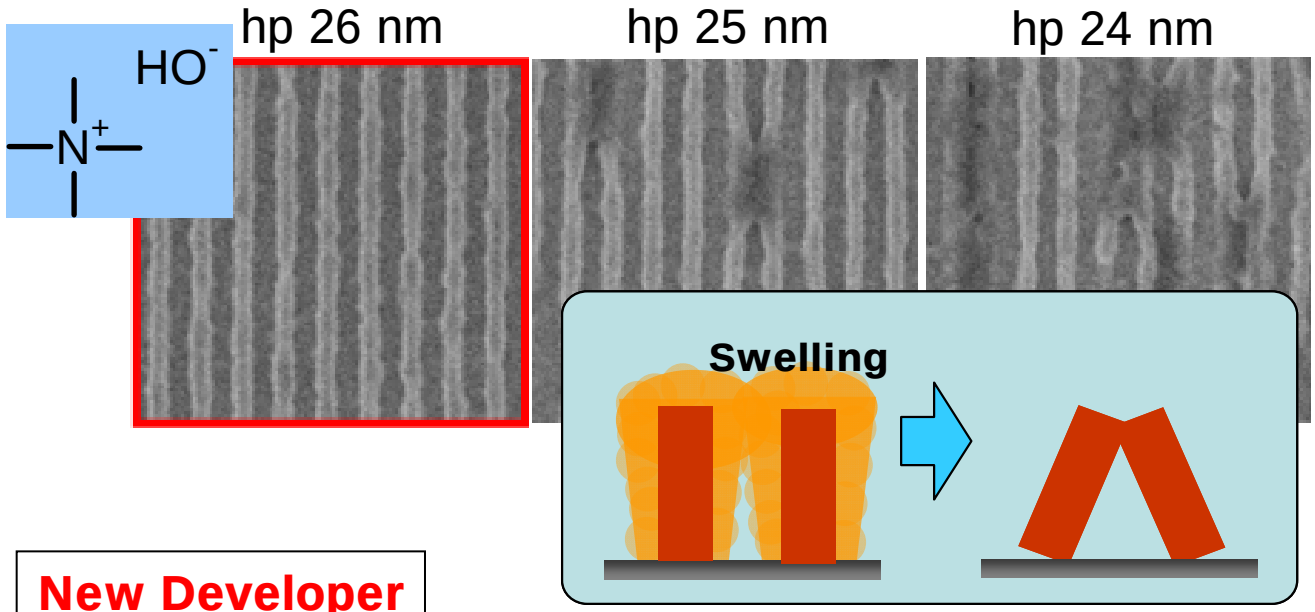


Sensitivity - LWR



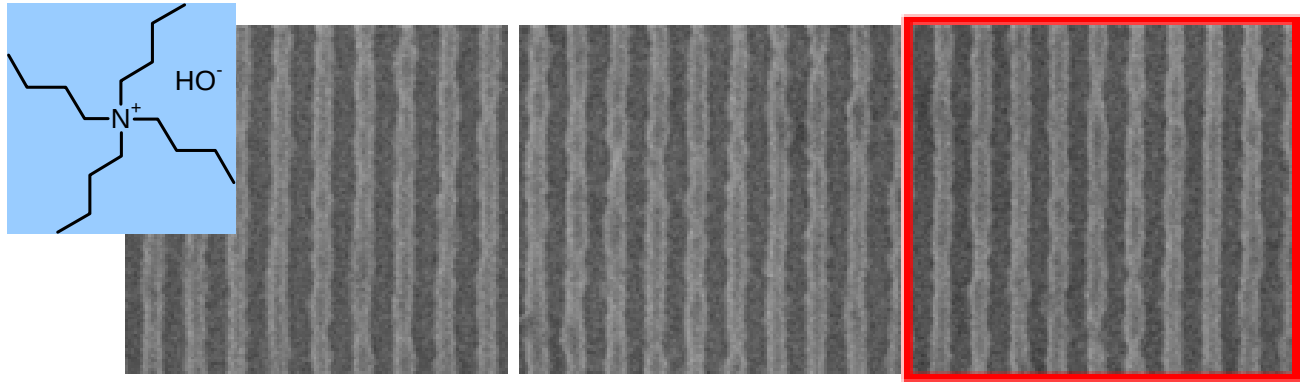
Sensitivity - Resolution

TMAH 0.26N (Tetramethyl Ammonium Hydrooxide)

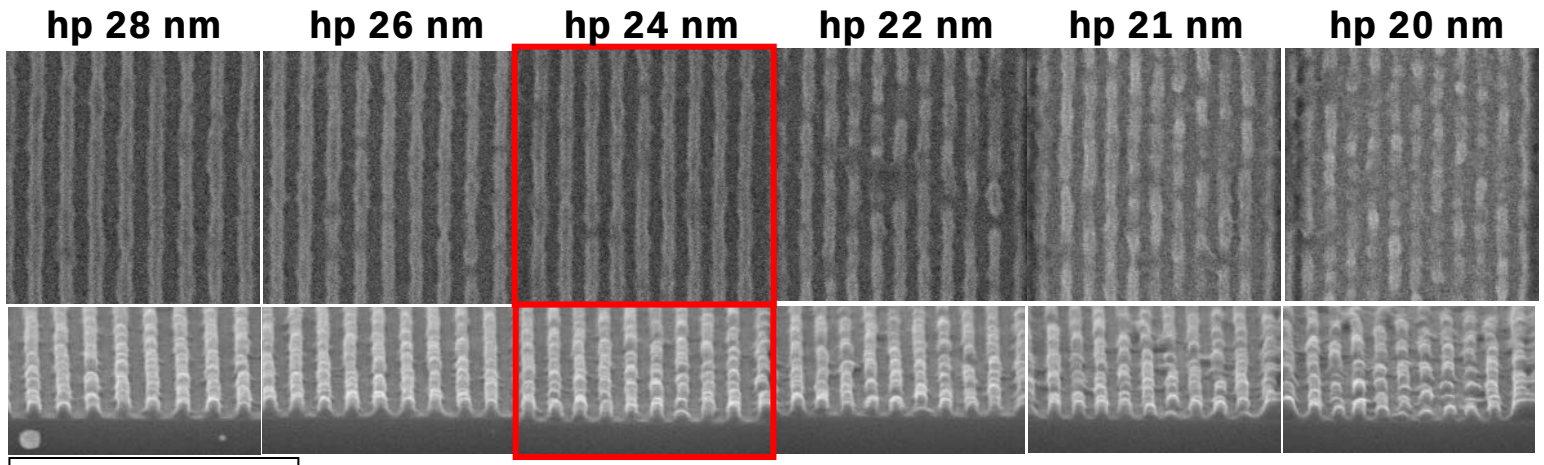


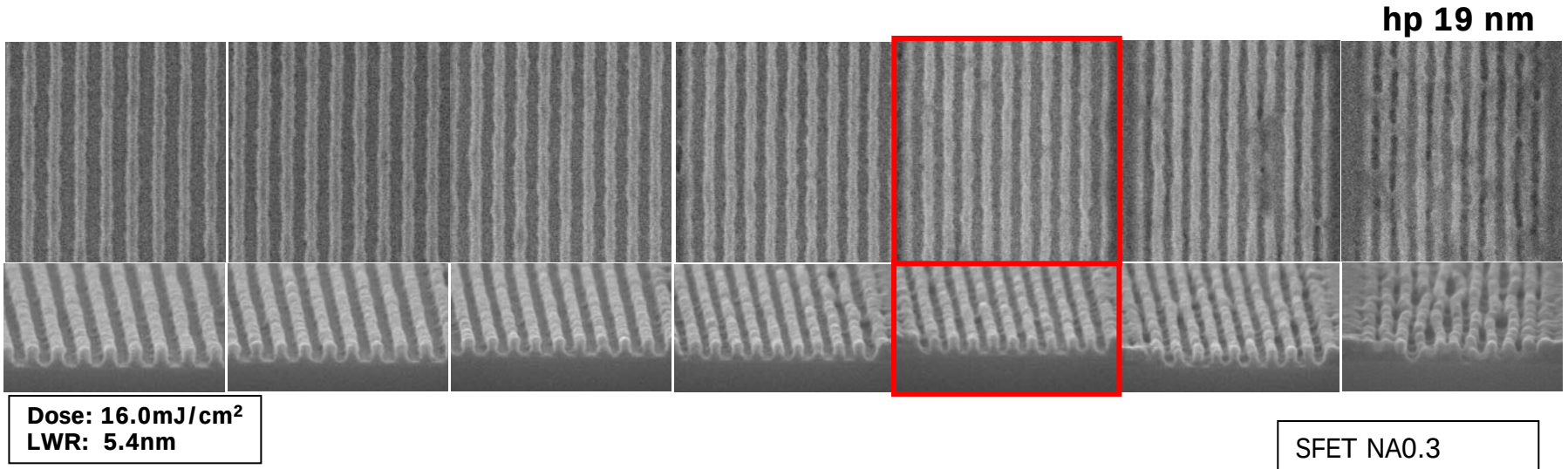
New Developer

TBAH 0.26N (Tetrabutyl Ammonium Hydrooxide)



Latest performance of EUV resist

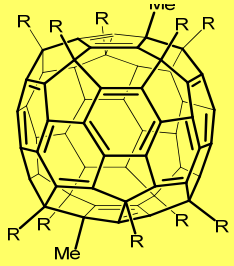


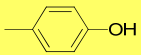


SFET NA0.3
Illumination: X-slit
50nm Thick.
Developer: TBAH

Molecular Resist（Fullaren derivatives）

M100



R = 

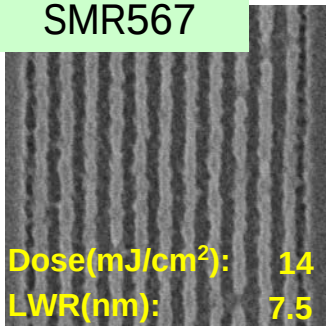
Protecting group: bulky ester

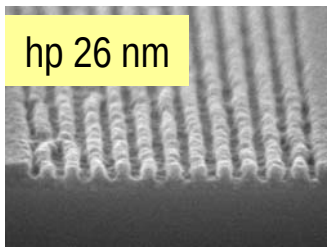
SMR567 based on M100

M100-bulky E/BBI-nf 30wt%/TOA 3wt%
Substrate: under-layer F (UL-F) 20nm
Film thickness: 50nm
SFET (x-slit)
PAB 110℃/PEB 110℃
Dev.: TMAH 0.26N 30 sec

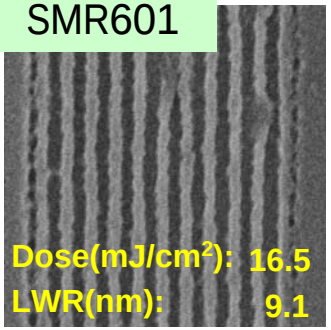
SMR567: 保護基の最適化
SMR601: 保護比率の増加

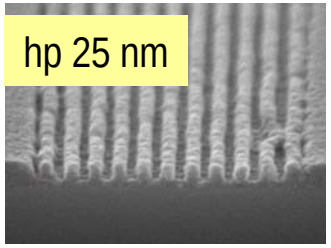
SMR567





SMR601

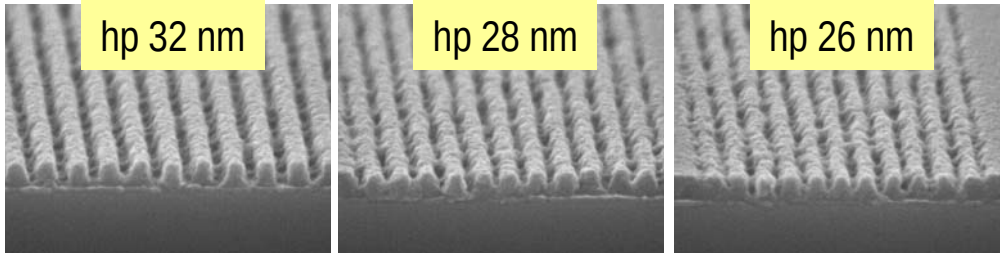




Cross sectiona view befere/after etching（SMR567）

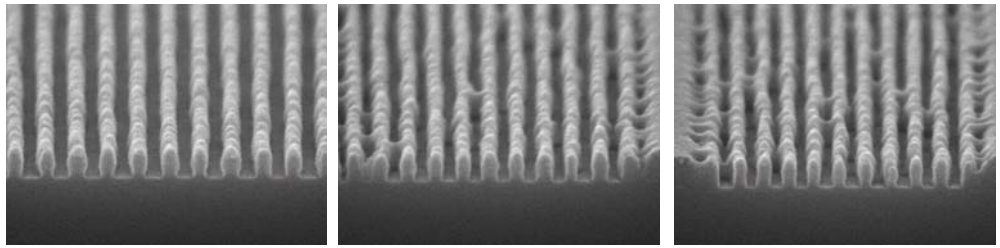
Litho-pattern

Resist(60nm^t)
/UL(20nm^t)

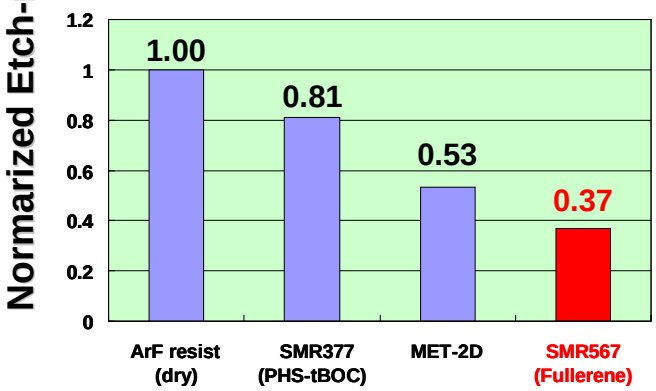


After Etching

Resist(60nm^t)
/UL(20nm^t)
/Poly-Si(50nm^t)
/SiO_2(4nm^t)/Si



Etcher: U-8150 (Hitachi)
Condition :Cl_2, 0.4Pa, 500W

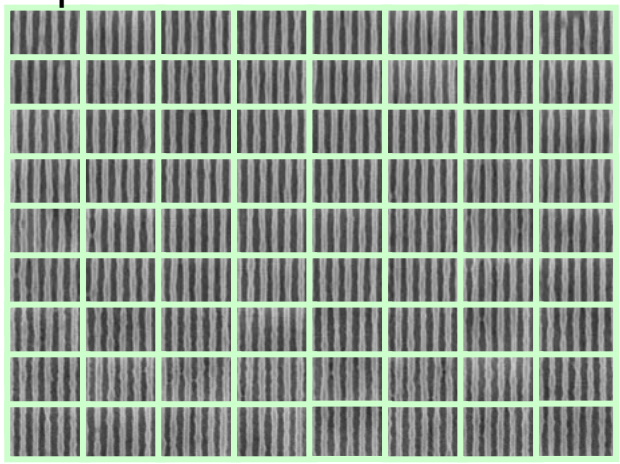


Full Field Exposure

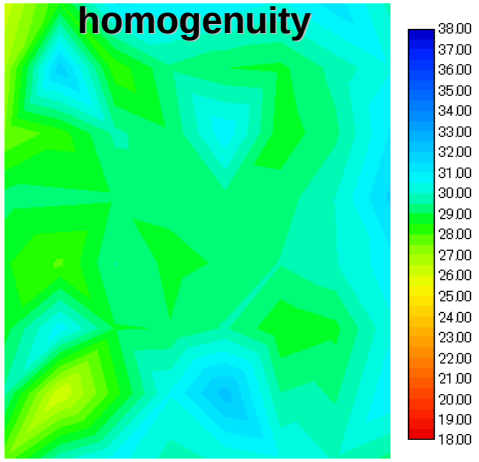
Performance of EUV1 (1)

CD accuracy

hp 28 nm

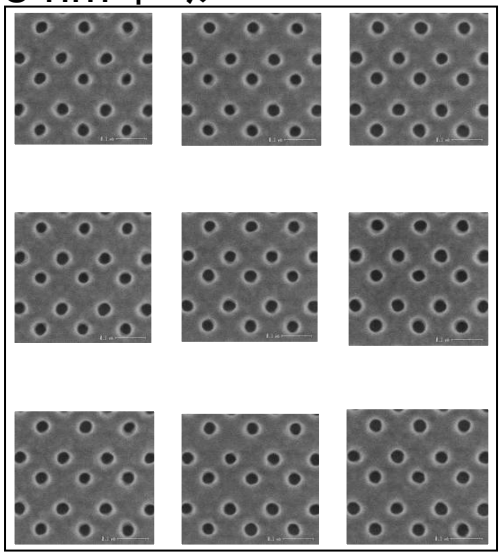


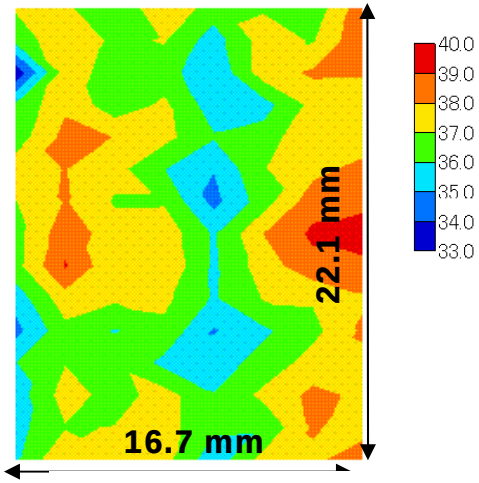
In-field homogenuity



Mean = 29.5 nm
3σ = 3.7 nm

35 nm ホール

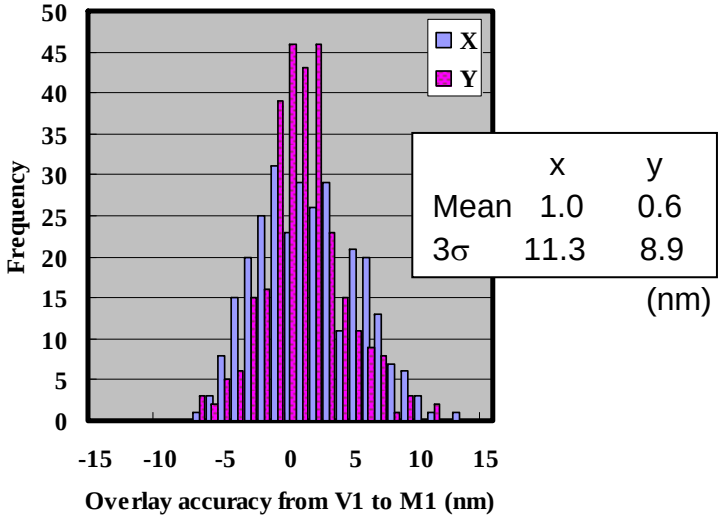




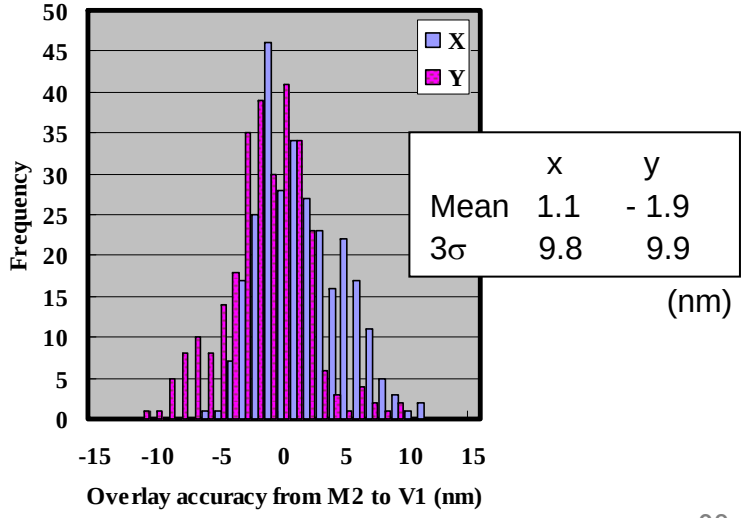
Mean = 37.0 nm
3σ = 3.3 nm

Overlay accuracy

Via 1 to Metal 1

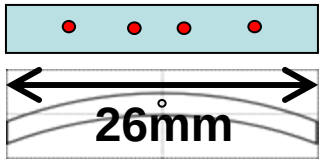


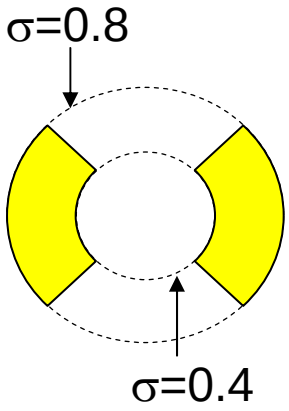
Metal 2 to Via 1



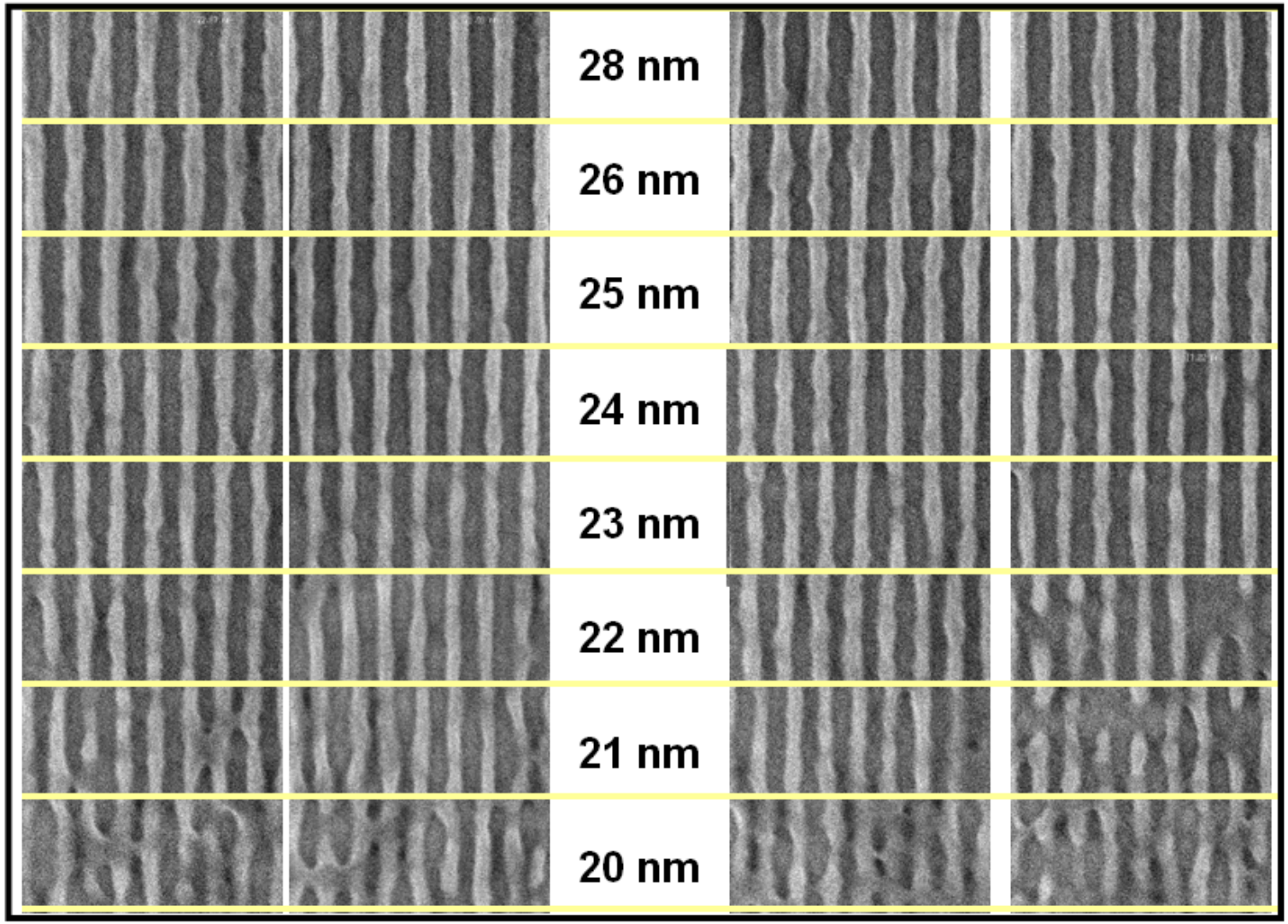
Performance of EUV1 (2)

Resolution performance by dipole illumination

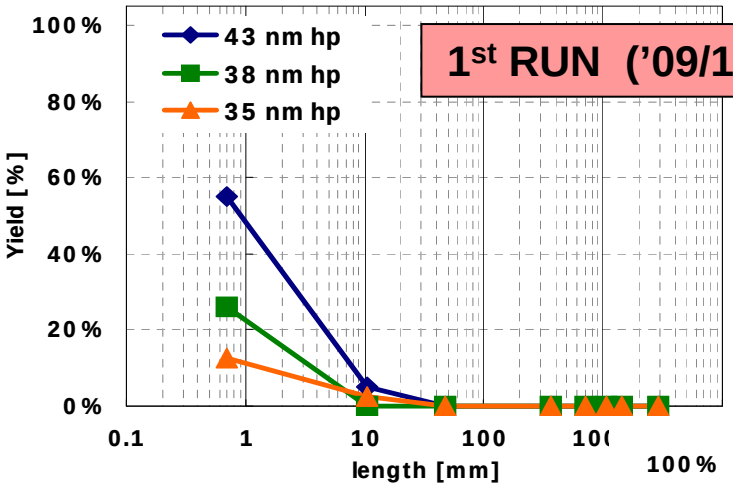




SSR4:
45 nm thick
Dose:
11 mJ/cm²

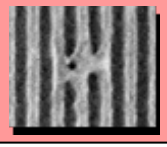


Yield improvement of hp 3X nm PL-TEG



1st RUN ('09/1)

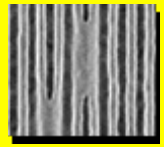
tiny bridge



SSR3

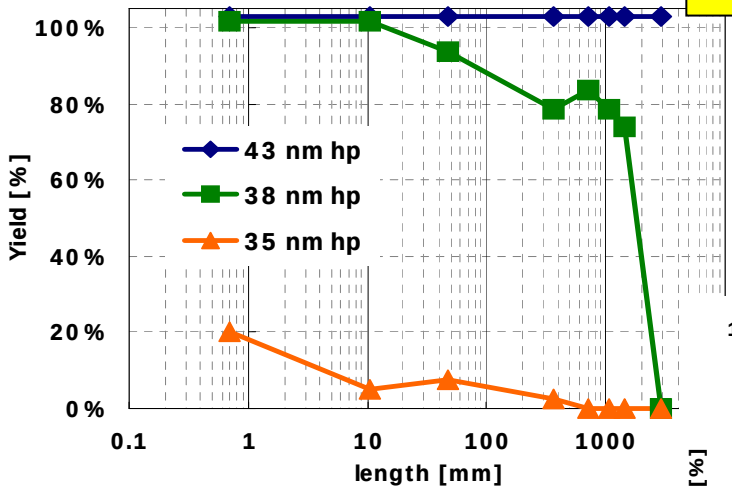
Yield was improved by resist performance

collapse

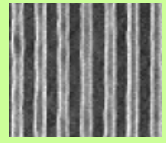


SMR73

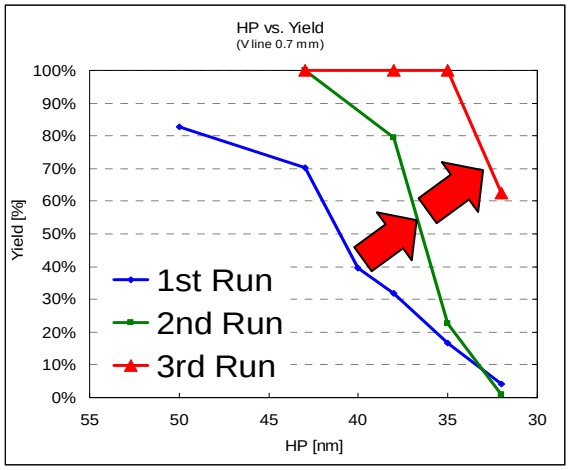
2nd RUN ('09/6)

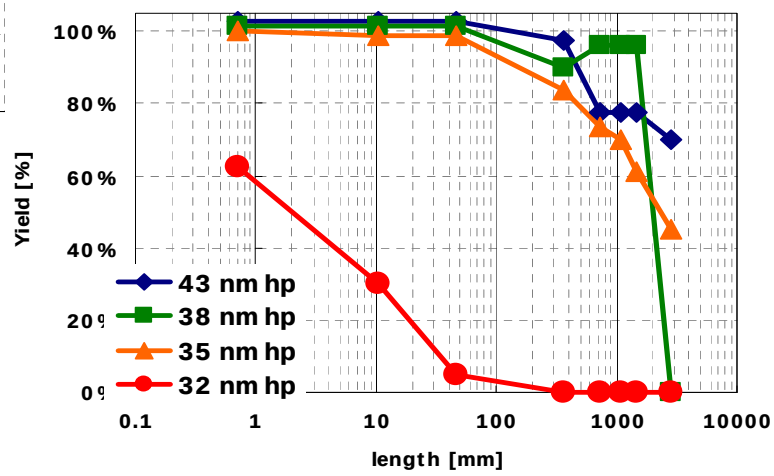


SSR4



3rd RUN ('09/10)





Summary

- History of Japan EUVL development was reviewed.
- Source power is approaching 100 W level based on understanding of plasma physics under the collaboration with university and national laboratories.
- Wavefront error of optics is drastically improved by introduction of new metrology techniques in this decade, and become to satisfy the requirement to pre-production exposure tool.
- EUV1 shows resolution of 22 nm hp with dipole illumination.
- Mask infrastructure is now developing at Selete.
  - Signal to noise ratio of actinic blank inspection tool (ABI) is improved. We applied ABI tool to whole-area bank inspection, and successfully demonstrated the sensitivity as small to 1.1nmH and 20nmW defect.
  - DUV (199 nm)-based pattern inspection technique is applicable to hp 2X by using polarized illumination and low reflectance absorber material.
  - Defect printability are studied using above infrastructures and calculation.
- Resist performance has improved steady based on the improvement of materials and processing technologies.
- We are now developing the α-stage EUVL processing, and will be transferred to β-stage processing in next phase and also manufacturing in company.
- We are now developing BEOL-TEG（hp35nm） process, and PL-TEG（hp3Xnm and hp2Xnm） process. We learn the issues for high volume production.

Acknowledgement

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The author thanks to all co-workers for assistance of presentation.